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Multi-Objective Optimization of Bio-Base Grease Using Hybrid Taguchi – Grey Relational Analysis

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Multi-Objective Optimization of Bio-Base Grease Using Hybrid Taguchi – Grey Relational Analysis

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A thesis submitted
in fulfillment of the requirements for the degree of
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2023

DECLARATION

I declare that this thesis entitled "Multi-Objective Optimization of Bio-Base Grease Using Hybrid Taguchi – Grey Relational Analysis" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis, and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master Mechanical Engineering (Automotive).

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DEDICATION

I dedicate this thesis to God Almighty, my Creator, strong pillar, source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program, and on His wings only have I soared. This work is also dedicated to my mother, Puan Bakiah Haji Samsuri, and my late father, Almarhum Haji Mohd Noh Bin Abdul Kader, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve. To my lovely long-life girlfriend, Ruzza Amran, who has been a constant source of support and encouragement during the Master's program. I am truly thankful for having you in my life. To my children AlHafizah Ain Hasanah and Arif Borhanuddin Al Autismi, who have been affected in every way possible by this quest. Thank you. My love for you all can never be quantified. God bless you.

ABSTRACT

Bio grease has gained increasing attention in recent years due to its promising benefits, which include being environmentally friendly, renewable, less toxic, and readily biodegradable. In recent years, numerous studies have been conducted to explore the potential of bio-based greases for industrial applications. This study aimed to create a novel bio-based grease with a viscosity comparable to a commercial, industrial lubricant. A multi-optimization strategy was utilized to achieve this goal, specifically the Taguchi methodology with grey relational analysis. A total of nine different samples were produced by combining non-edible base oils and different percentages of beeswax thickener and hBN additives. The optimal blend was then tested for its coefficient of friction and time durability. A greater endurance over time will reflect reliability for application, especially in robust industries. The study employed the Taguchi optimization technique with grey relational analysis to evaluate how diverse design parameters influenced the friction coefficient. According to the findings, the optimal blend of ingredients was 92.5% castor oil, 5% beeswax thickener, and 2.5% hBN additives, resulting in the highest friction coefficient that falls within the range of conventional industrial lubricants. This study contributes to the growing body of research on bio base greases and their potential for industrial applications and demonstrates the effectiveness of a multi-optimization approach using Taguchi with Grey relational analysis. By pursuing this effort, developing and implementing innovative approaches centred on resource conservation will lead to a sustainable future where we can thrive without depleting our planet's limited resources.

ABSTRAK

Bio gris telah mendapat perhatian yang semakin meningkat dalam beberapa tahun kebelakangan ini kerana potensi faedahnya termasuk mesra alam, boleh diperbaharui, kurang toksik dan mudah terbiodegradasi. Dalam beberapa tahun kebelakangan ini, banyak kajian telah dijalankan untuk meneroka potensi gris berasaskan bio untuk aplikasi industri. Kajian ini bertujuan untuk mencipta gris berasaskan bio baharu dengan kelikatan yang setanding dengan pelincir industri komersial. Strategi pengoptimuman berbilang telah digunakan untuk mencapai matlamat ini, khususnya metodologi Taguchi dengan analisis hubungan samar-samar. Sebanyak sembilan sampel berbeza dihasilkan dengan menggabungkan minyak asas tidak boleh dimakan dan peratusan berbeza pemekat lilin lebah dan bahan tambahan Heksagonal Boron Nitrida (hBN). Campuran optimum kemudiannya diuji untuk pekali geseran dan keutuhannya. Daya tahan yang lebih tinggi dari masa ke masa akan menunjukkan kebolehpercayaan untuk aplikasi, terutamanya dalam industri. Peyelidikan menggunakan teknik pengoptimuman Taguchi dengan analisis samar-samar untuk menganalisis kesan parameter reka bentuk yang berbeza ke atas pekali geseran. Keputusan menunjukkan bahawa gabungan 92.5% minyak jarak, 5% pemekat lilin lebah, dan 2.5% bahan tambahan hBN, menghasilkan pekali geseran tertinggi, iaitu dalam julat pelincir industri konvensional. Kajian ini menyumbang kepada pemacu penyelidikan yang semakin berkembang tentang pelincir bio dan potensinya untuk aplikasi industri dan menunjukkan keberkesanan pendekatan pengoptimuman berbilang menggunakan Taguchi dengan analisis samar-samar. Dengan usaha ini, diharap dapat membangun dan melaksanakan kaedah inovatif yang berpusat pada pelestarian sumber yang membawa kepada masa depan yang mampan di mana kita boleh berkembang maju tanpa bergantung sepenuhnya terhadap sumber terhad planet kita.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	-	Analysis of Variance
AISI	-	American Iron and Steel Institute
ASTM	-	American Society of Testing of Material
COF	-	Coefficient of Friction
CBN	-	Cubic Boron Nitride
D,d	-	Diameter
DF	-	Degree of Freedom
GRA	-	Grey Relational Analysis
hBN	-	Hexagonal Boron Nitride
MQL	-	Minimum quantity lubrication
MS	-	Mean Squares
OM	-	Optical Microscope
S/N	-	Signal-To-Noise
SST	-	Total Sum of Squares
TGRA	-	Taguchi Grey Relational Analysis
	-	
μ	-	Coefficient of friction miu
T	-	Torque = Force multiply by radius
W	-	Weight
R	-	Radius

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CHAPTER 1

INTRODUCTION

1.1 Background

The phrase "green lubricant" refers to lubricants made from natural, plant-based sources. The demand for lubricants in industrialized nations is substantial, and the production of these lubricants on a large scale is a top priority for the lubrication industry due to the potential for depletion of natural resources and the associated economic impact (Panchal et al., 2015). The Hubbert peak theory (Ahmed et al., 2014) anticipates that the decline of oil production is imminent due to oil depletion. Given the finite nature of Earth's resources, the amount of fossil fuel within the planet is limited. As the majority of the world's energy resources and consumption relies on fossil fuels, it is essential to consider future generations and pursue sustainable development in the field of tribology (Koji, 2019).

Therefore, the economic considerations and the need for price stability favour using lubricants made from renewable sources over those made from petroleum (Yadav, Singh and Negi, 2021). Therefore, non-edible oil is evaluated as a potential substitute for synthetic oil base stocks in specific lubrication applications (Almasi et al., 2021). The utilization of non-edible oils as lubricant bases can help decrease the depletion of natural resources. Additionally, the use of non-edible oils as lubricants can offer advantages in terms of energy independence and security. These oils are non-toxic and biodegradable, which reduces the risk of environmental harm in case of accidental spillage or waste disposal (Syahir et al., 2017).

Sustainable lubrication is a critical component of sustainable development, and my area of research focuses on bio-grease. The current emphasis in sustainable transport is to ensure the sustainability of the delivery system through the implementation of the 6R methodology: reduce, remanufacture, reuse, recover, recycle, and redesign. Determining the ideal processing parameters is a crucial aspect of the plastic injection moulding industry due to its significant impact on the quality and cost of plastic parts (Mehat, Kamaruddin and Othman, 2014). However, optimizing the parameters of the grease formulation process can be challenging as multiple quality characteristics are considered in the evaluation.

This study proposes a hybrid optimization method that combines the Taguchi parameter design and grey relational analysis to account for multiple quality characteristics. The proposed method is tested using a plastic gear and demonstrates its effectiveness in controlling production parameters during the manufacturing of bio-based grease. The optimal combination of process parameters that minimizes wear and provides the best coefficient of friction is determined. The case study shows that the proposed optimization method can produce bio-based grease with selected controlled parameters that are lower than those of the main experiment. Nowadays, lubrication systems are extensively employed, and they have emerged as a crucial aspect in enhancing engine efficiency while simultaneously mitigating issues related to friction and wear. Generally, lubricants are utilized to reduce frictional forces between surfaces in most practical applications, as opposed to altering the surfaces themselves.

a) Besides fluctuating oil prices and the declining global crude oil supply, the desire to safeguard the environment from pollution has prompted researchers to explore alternative lubricants (Rahman and Wahid, 2021).

b) Non-edible oil is a viable alternative due to its environmentally friendly, non-toxic, and biodegradable properties. Vegetable oils possess low-level anti-corrosion properties (Syahrullail *et al.*, 2013).

c) The Non-edible can be used as a viable option alternative lubricant since it aids in the reduction of the coefficient of friction (COF) (Srinivas *et al.*, 2021).

Therefore, it is imperative to investigate the practicality of utilizing non-edible oils as a replacement for conventional lubricants by analyzing their frictional and wear characteristics and determining their suitability for industrial applications. Given the advantages of using natural oil-based lubricants, such as sustainability and eco-friendliness, evaluating their tribological properties as a potential substitute for mineral oils is crucial. This study aims to examine the feasibility of using natural oil-based lubricants in automotive applications, in contrast to the conventional lubricants presently utilized. The experiment is performed using a four-ball tester setup to ascertain the frictional and wear properties.

1.2 Problem Statement

The goal of this research is to develop a multi-objective optimization technique for bio-base grease using hybrid Taguchi–Grey relational analysis. The study investigated the optimal combination of factors for developing a bio-based grease to achieve better performance in terms of cost, environmental friendliness, and stability under high-temperature conditions. The performances of the proposed bio-based grease were evaluated using Taguchi's orthogonal array, multiple regression analysis and gray relational analysis. The results of this research provided insights into the use of bio-based materials in the

manufacture of high-performance greases and will offer a viable alternative to traditional petroleum-based greases.

The reliance on conventional lithium bases was already challenging as demand for EV batteries grew. This also gives a price that is exponentially not business-friendly. The other concern is also due to the toxicological of lithium grease that imposes carcinogenic, mutagenic effects on humans and the environment (Concepts, 2022).

1.3 Study Objective

The primary purpose of this research is to advise a systematic and effective method to create a non-edible vegetable oil-based grease, using castor, jatropha, and neem oils with cosmetic grade beeswax thickener and hexagonal boron nitride nano (hBN) additive, for advanced equipment such as high-speed railway axle box bearings. The grease needs to be reliable, environmentally friendly, and sustainable for high speeds, up to 200 km/h and possibly even higher. The key goal is to produce grease with good lubricity and mechanical stability, as mechanical stability is crucial in determining the consistency of the grease when subjected to mechanical stress. In order to attain this goal, the specific objectives are:

a) to produce a new bio-grease with good lubricity and mechanical endurance using hybrid Taguchi Grey relational method equal to that of commercially available grease, and
b) to compare the COF of the manufactured bio-grease with commercially available grease.

1.4 Scope of Studies

The scopes of this study are as follows:

1. Create a design of experiment in order to evaluate the optimization of three non-edible oil with a variable quantity of base oil, additive and thickener percentage.
2. Produce bio-based grease formulated from the Taguchi DOE method using three bio base non-edible oil selected.
3. Measure how much data of steady-state coefficient of friction and the time taken for the durability period using ASTM D2266.

1.5 Contribution of Studies

The research presented in this dissertation has likely enhanced the comprehension and knowledge of tribology among the academic and scientific community. Specifically, the study may have contributed to the following areas of knowledge and understanding:

1. Production of bio-greases: The study has likely contributed to enriching knowledge of how different base oils, thickener percentages, and additive percentages can be merged to formulate bio-greases with different tribological properties. This information can be utilized to develop bio-greases that are tailored to particular applications and performance criteria.

2. Evaluation of tribological properties: The study has likely contributed to understanding how to evaluate the tribological properties of bio-greases through methods like conducting coefficient of friction tests and assessing mechanical

stability. The knowledge can aid in developing more reliable and accurate methods for assessing bio-greases' performance.

3. Comparison of bio-greases: The study has likely contributed to understanding how diverse bio-greases can be assessed and ranked according to their effectiveness. This knowledge can aid in identifying the most promising bio-greases for specific applications and guide future research on the development of new bio-greases.

Overall, the research represented in the table above has likely made a significant contribution to the field of tribology and has helped to advance the knowledge and understanding of bio-greases and their applications.

The research discussed in the preceding paragraph has probably made a remarkable impact on the area of tribology and has contributed to the enhancement of knowledge and comprehension of the utilization of bio-greases (Razak and Ahmad, 2021).

1.6 Thesis Outline

Based on the previously presented objectives and the proposed approach before, this dissertation is made up of five (5) chapters, the contents of which are summarized as follows:

- Chapter 1. Introduction. This chapter presents the background of the study, research problems, objectives, scope, contributions, and important of the research.
- Chapter 2. Literature Review. This chapter provides a review of the current state of knowledge on bio-based lubricants, including their properties,

applications, and potential advantages over mineral oil-based lubricants. It also discusses the role of additives such as hexagonal boron nitride and beeswax in improving the performance of bio-greases.

- Chapter 3. Methodology. This chapter describes the experimental setup used and the procedure for manufacturing and evaluating the tribological properties of the bio-grease samples, including details on the materials, equipment, and test procedures used.
- Chapter 4. Results and Analysis. This chapter presents and discusses the results of the tribological testing of the bio-grease samples, including data on the coefficient of friction, mechanical stability, and other relevant performance characteristics. In addition, this chapter incorporates an analysis of the statistical data and a comparison of the performance of the different bio-grease manufactured.
- Chapter 5. Conclusion and future work. This chapter summarizes the main conclusions of the study and discusses the potential applications and implications of the results. It also suggests areas for future research and development of bio-based lubricants.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Bio grease is a type of grease that is derived from biological sources rather than petroleum. It is typically made from renewable resources such as vegetable oils, animal fats, and waste cooking oils. Bio grease is biodegradable and environmentally friendly, making it an attractive alternative to traditional petroleum-based grease. In addition to its environmental benefits, bio grease has good lubricating properties and can be used in various applications, including the lubrication of bearings, gears, and other mechanical components. Utilities providers and regulators are putting more emphasis on decreasing pollutants because it represents a vital indicator of a power-efficient machine. For strategic planning and development of green transport fuel and lubricant, technical and scientific fraternities need to broaden a powerful technique to properly and correctly evaluate traditional carbon gas and lubricants that aren't sustainable in the device. With comprehensive and correct test-gathered information, corrective and preventive solutions for non-biodegradable reliant decrease may be planned and performed efficaciously and in a timely and effective way.

2.1.1 Thickener

Thickener is a chemical compound used in grade formulation as one of the main components. This part makes it possible to satisfy the required consistency or hardness levels and other performance specifications. The thickening agent may be an inorganic or

an organic substance. Organic thickeners may be soap-based or non-soap based, whereas non-soap-based inorganic thickeners are. Applications such as high-temperature environments and non-soap thickeners are also becoming more common. The thickener's primary purpose is to maintain contact with or maintain lubrication while it moves or leaks out under the force of gravity. According to Suhaila *et al.* (2018), beeswax is a natural material produced by draining from the bee's honeycombs. It has the characteristics of being insoluble in water. Beeswax was chosen as the thickener of the grease composition in this experiment.

Figure 2.1: Beeswax

2.1.2 Advantages of Beeswax

For lubrication purposes, beeswax has excellent attributes because it is non-toxic, non-corrosive, and has long-term chemical stability and decreased production costs (Suhaila *et al.*, 2018). Beeswax also can improve water resistance over lithium greases and good shear stability.

2.1.3 Additives

Adding a grease additive to the base oil aims to improve the performance properties of that base oil while also providing the finished oil compound with completely

new performance characteristics. Additives are chemical compounds added to lubricating oils to give specific properties to finished oils (Larsson *et al.*, 2021). Some additives impart new and useful properties to the lubricant, while others enhance the existing properties. Still, others slow the rate at which undesirable changes in the product occur throughout its service life. Improved lubricating oil performance characteristics due to additives have significantly improved prime movers and other industrial machinery.

Throughout the grease's lifetime, the additive can also assist in slowing the rate of decomposition. The respective speciality may be in a specific type of additive. The additives used in grease lubrication can perform a variety of functions. These primarily enhance desirable properties, replace undesirable properties, and transmit new information and materials. Chemical additives that are commonly used include high-pressure, wear-resistant, and friction-reducing agents. Hexagonal boron nitride nanoparticles were used in this research.

Figure 2.2: Hexagonal Boron Nitride Nanoparticles

2.1.4 Advantages of Hexagonal Boron Nitride Nanoparticle

Hexagonal boron nitride nanoparticles can increase the coefficient of friction of lubricating fluid while decreasing wear. Hexagonal boron nitride nanoparticles are